POSSIBLE USE OF WATER CONDENSED FROM A VIABLE CABIN ATMOSPHERE FOR DRINKING AND OTHER DIETARY PURPOSES

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One of the simplest ways of regenerating water during space flights is the use of a condensate of water vapor obtained from the cabin air by physical drying [4, 5].

The atmosphere of living rooms is contaminated by a number of volatile substances, the source of which may be man himself or the materials used in the construction and partitioning of the cabin, in electrical insulation, and other purposes. Most of these substances pass into the condensate when water vapor is condensed, making it unsuitable for direct use as drinking water.

In this paper we describe the results of a preliminary toxicologic investigation of condensate of atmospheric vapor from a hermetically closed cabin obtained while a person stayed in it for several days, and of an investigation of the effectiveness of its purification by means of ion-exchange resins and activated charcoals (KU-2, EDE-10p, AV-27, BAU, and so on). Suitability of water obtained from the condensate for drinking purposes was investigated in a long-term experiment on young rats, after which the regenerated water was used in a human diet. /401

The material subjected to toxicologic investigation was a condensate obtained during an experiment, which lasted for several days, in a pressure chamber using human subjects, the air being regenerated by a supply of fresh oxygen and by means of a chemical lime absorbent. The chemical composition and hygienic properties of the condensate and the water obtained from it are given in Table 1. Examination of the data given in Table 1 shows that the condensate contained large quantities of ethyl alcohol, due to the fact that the subjects used toilet articles containing ethanol. Since this is poorly absorbed by ion-exchange resins and charcoals, nearly all the alcohol contained in these toilet preparations found its way into the regenerated water.

In the course of the experiment the concentration of ethyl alcohol in the condensate varied within wide limits (up to 3-4 g/liter) depending on the intensity of its entry into the cabin atmosphere. The oxygen demand of the condensate, which was mainly determined by its ethanol concentration, varied within equally wide limits. Accordingly, a series of experiments with 0.5% ethanol solution was included in the toxicologic investigation.

To obtain preliminary toxicologic data for the condensate, frog (Rana temporaria) embryos at the late blastula stage [1] were used. The embryos were kept in batches of 100 each in tap water (control), in purified and unpurified condensate, and also in 0.5% ethanol solution in tap water.

TABLE 1. Chemical Composition and Hygienic Properties of Condensate Before and After Purification by Absorbents

Indices of water and contaminants contained in it	Indices of water and amount of contaminants	
	Before purification	After purification
Odor, points	3—4	1
Color, deg.	—	3
Transparency (test type), cm.	20	>30
Turbidity	Precipitated during storage	None
Taste	Not detected	Traces of alcohol
pH	7.3	7.2
Cations, mg-eq/liter	2.25	0
Anions (fatty acids), mg-eq/liter	2.5	0
Ethyl alcohol, mg/liter	~300	294
Oxygen demand, bichromate, mg O_2/liter	237	204
Including that due to Ethanol	—	196
Other contaminants		8
Oxygen demand, permanganate, mg O_2/liter	70	40
Nitrogen (Kjeldahl), mg/liter	70	0
Ammonia, mg/liter	75	0—0.3
Hydrogen sulfide and mercaptans, mg/liter	1.5	0
Formaldehyde, mg/liter	Traces	0
Acetaldehyde and other aldehydes, mg/liter	20	0
Amines and amino acids, mg/liter	Traces	0
Ketones, mg/liter	20	0
Calcium, mg/liter	16	0
Magnesium, mg/liter	7	0
Nitrite nitrogen, mg/liter	0.4	0
Nitrate nitrogen, mg/liter	0.1	0
Chlorides, mg/liter	Traces	0
Sulfates, mg/liter	Traces	0
Copper, mg/liter	3.25	0
Iron, mg/liter	Traces	0
Coli titer	Over 500	Over 500
Total bacterial count	No growth	No growth

The embryos developed identically in the purified condensate, in water containing ethanol, and in the control series, and by the 5th day of the experiment they had changed into free-swimming larvae. Their subsequent development, which was examined for the next 10 days, showed no difference between the control and experimental batches. Development of the embryos kept in unpurified condensate ended at the end of the first or beginning of the second day of the experiment at the late gastrula or neurula stage, and later all the embryos died.

One of the causes of this high toxicity of the condensate could be ions of copper and, perhaps, of other metals, for condensation of the water vapor took place on a metal surface. To test this hypothesis, an additional experiment was carried out using unpurified condensate in which all cations were replaced /402 by sodium ions by means of the cation-exchange resin KU-2.

In these experiments 90% of the embryos died at the same stage as in the series with unpurified condensate, 5% of the embryos showed retardation in size and developmental defects of the caudal region at the moment of emergence from the membranes, and only 5% of the embryos completed their development without /403 visible disturbances and shed the egg membranes at the same time as the controls.

These results show that the well-marked toxic effect of the unpurified condensate is not due to contamination with copper or other ions so much as to the other substances contained in the condensate. At the same time, the results demonstrate the great effectiveness of the methods used to purify condensate. Ethyl alcohol had no significant effect on development of the embryos, whether acting alone (in 0.5% solution) or in possible combination with unidentified contaminants in the purified condensate.

In the next experiments to study the effect of drinking regenerated water, male albino rats initially weighing 170-180 g were used. The experimental animals were divided into four groups, with 15 rats in each. The animals of Group 1 received purified condensate, with the hygienic properties indicated in Table 1, to drink. The animals of Group 2 received the same condensate with the addition of mineral salts to correspond to their content in Moscow tap water, those of Group 3 received tap water with the addition of 0.5% ethyl alcohol, and the rats of Group 4 received plain tap water (controls). The experiment continued for 105 days.

The state of the animals was judged from their behavior, the quantity of water and food consumed, changes in body weight, and the hemoglobin concentration and erythrocyte and leukocyte counts in the peripheral blood.

During the experiment the total volume of water drunk by the animals of the control group was 30 liters. The animals of the experimental groups drank 26 liters of purified condensate, 20 liters of condensate with the addition of mineral salts, and 18 liters of water with the addition of alcohol. Comparison of these results demonstrates the selective reticence of the experimental animals to drink water containing alcohol and also condensate with corrected salt composition.

The general condition of the experimental animals, their behavior and food consumption, and the dynamics of their body weight throughout the experimental

period were indistinguishable from those in the animals of the control group. The changes in blood morphology in the animals of the control and experimental groups were within normal physiological limits and no differences were found between the groups.

At the end of the experiment 40 rats were autopsied. The animals were killed with ether vapor. The relative weights of the adrenals, thymus and spleen were determined at autopsy. Macroscopic investigations were made of the mucous membranes of the pharynx, larynx, trachea, gastro-intestinal tract and urinary bladder. Observations were made on the state of the heart, lungs, /404
liver, spleen, kidneys and adrenals.

On five animals of each group microscopic investigations were made of the liver, kidneys, proximal and distal portions of the small intestine, brain, pituitary, thyroid, and adrenals. The organs taken for examination were fixed in 10% neutral formalin and stained with hematoxylin-eosin.

Analysis of the total body weight of the rats and the relative weights of the adrenals, thymus and spleen showed no statistically signficant difference between the controls and experimental groups. The slight, nonspecific pathological changes found in the experimental animals were also observed in the control animals receiving tap water to drink. Because of the identical incidence of these changes in the control and experimental groups, they cannot be attributed to the quality of the fluid consumed.

The results of this experiment show on the whole that drinking condensate purified by absorbents or drinking tap water with the addition of 0.5% alcohol by animals for 3.5 months caused no pathological changes in the rats and was not reflected in their growth. It was therefore decided to test the use of purified condensate in human diet.

For the experiment on human subjects water was regenerated from condensate obtained from a hermetically closed model of a spacecraft cabin in which people were kept for several days. The air was regenerated by chemical methods. The system for collecting and purifying the condensate was constructed from neutral materials, and no ethyl alcohol was used in the cabin during the experiment.

The regenerated water used for drinking purposes had the following chemical composition and hygienic indices:

TABLE 2

Indices of Water	Result	Indices of Water	Result
Transparency, cm	Over 30	Nitrogen (Kjeldahl), mg/liter	0.84
Odor, points	1	Ammonia, mg/liter	0.3
Color	Colorless	Ketones, mg/liter	0
Residue	Absent	Aldehydes, mg/liter	0
Taste	Distilled Water	Indole, mg/liter	0
pH	6.8	Amines + Ammonia, mg/liter	0.5
Cations, mg-eq/liter	0	Hydrogen Sulfide and	
Anion, mg-eq/liter	0	Mercaptans, mg/liter	0
Oxygen Demand		Ethyl Alcohol, mg/liter	Traces
mgO_2/liter			
Permanganate Method	3.6		
Bichromate Method	14.0		

During the experiment two subjects stayed in the closed cabin. The condensate of water vapor formed in the refrigeration unit was collected in a special receiver, passed through absorption columns, and its mineral composition was corrected by the addition of sodium, calcium and magnesium salts. /405

After analysis, the purified condensate was given to one of the subjects to drink directly or in the form of tea. The other subject drank only tap water.

During the six days of the experiment the first subject drank 6100 ml of regenerated water and the other drank 6550 ml of tap water. The subject drinking regenerated water observed no special differences in its taste or other properties.

In other experiments we repeatedly exchanged the tap water used for making tea on certain days for regenerated water, unknown to the subject. On subsequent interrogation, the subjects were never able to detect any difference between the tap water and regenerated water.

The results of physiological investigations during the experiment, together with the results of careful clinical examination of the subjects before and after the experiment, showed no change in the state of the first subject which could be attributed to drinking regenerated water.

The method of purifying condensate of water vapor from the living cabin by means of absorption, as used in these experiments, thus proved an effective means of obtaining drinking water under conditions simulating the spacecraft cabin.

The quality and potability of water used for drinking purposes under terrestrial conditions are governed by State Standards governing the choice of source of water supply and quality of water. In practice, under these conditions the potability of water is determined by the extent to which its characteristics satisfy the requirements of the State Standard for the composition of water and the hygienic state of the water source.

However, when determining the potability of water regenerated from human metabolic products (and, in the future, from metabolic products of other biological objects included in the ecological system), it would be incorrect to be governed entirely by the requirements of the existing health regulations for water supplies. These requirements, reflecting the natural origin of soil waters and the special nature of sources responsible for their polution, cannot correspond fully to the provision of standards for the quality of artificially regenerated water. This is particularly true of the hygienic indices of water from springs.

In relation to regenerated water, when its composition is considered by /406
itself, since the water is known to be of artificial (and not natural) origin, the modern physiological and hygienic principle of assessing the quality of drinking water from the standpoint of its effect on the living organism [3] becomes particularly important. On the basis of this principle, the hygienic standards governing the composition and quality of drinking water must be distinguished from its indices characterizing the hygienic state of the source of the water. The latter are particularly in need of correction as applied to the evaluation of regenerated water, because in this case the concept of water source is completely devoid of its original hydrogeological significances.

As an example of these hygienic indices we may consider the oxygen demand. The requirements concerning oxygen demand restrict the allowable scale of contamination of the water source by products of natural bacterial decomposition of organic matter, a factor which is also associated with the possibility of bacterial contamination of the water. In the closed cycle of physico-chemical regeneration of water from water vapor condensate, sources of contamination of this character can be practically eliminated.

Meanwhile, under certain conditions alcohol may be present in the condensate, giving the water a high oxygen demand. The high oxygen demand of a water known to be contaminated with alcohol only cannot, of course, be considered in the traditional light as an index of the unsatisfactory hygienic state of the water supply. In this case the oxygen demand becomes essentially a criterion of the alcohol content, for which there is no hygienic standard in drinking water, although such a standard may be necessary in certain cases of water regeneration from condensate.

The situation may be the same also in connection with the content of nitrates and nitrites in water, for with certain methods of water regeneration (for example, from salt-containing nutrient media for plants) these cannot be regarded as indirect evidence of organic pollution. In this case the permissible concentration of these salts in the water must be revised, if it is to be used as a hygienic standard, from the standpoint of their effect on the human body.

These examples show that the existing requirements concerning the quality of drinking water must be supplemented by others allowing for the special fea-

tures of water circulation when it is regenerated in a closed system. Besides the usual demand that the permissible contaminants are harmless, it is also desirable to pay heed to the question of standardization of the concentration of "useful chemical ingredients" in water, a term introduced by P. Ye. Kalmykov [2]. Clearly, such a standard (for trace elements, for example) cannot be introduced without analysis of the movement of these ingredients along other, /407
parallel channels of the circulation of matter.

One of the problems in quality standardization of regenerated water is the establishment of supplementary standards and indices related to the special features of the water sources and the technology of its production. Because of differences between sources and technological methods of regeneration of water, these indices may likewise differ. For example, the indices of water quality differ if it is regenerated from metabolic products, from the decomposition of hydrogen peroxide, or from combustion of oxygen in fuel elements.

Because of this variety of sources and the inconstancy of composition of possible contaminants in the water when regenerated by different methods, the only reliable basis for determining potability of regenerated water is by direct investigation of its biological properties and its effects on the human body by consideration of each concrete method of regeneration.

One of the most general biological properties of water under terrestrial conditions is its property of being a life environment, and the evaluation of water with relation to this property must, in our opinion, be an essential element in the system of criteria used to determine the fitness of regenerated drinking water.

From the technical point of view this criterion can be easily determined by cultivating a series of animals and, perhaps, plants also in the water to be tested. The greatest difficulty here is that, of the tremendous number of possible zoological, botanical and microbiological objects, it is necessary to select the minimum which will suffice for enabling the biological suitability and harmlessness of the water to be established. Individual organisms and populations, as well as isolated organs can be used as such test objects.

A biological control of the quality of regenerated water along these lines may perhaps play an essential role during the development of different variants and stages of the technological process of water regeneration. In this connection, methods of biological testing of water quality in use at the present time are in need of additional study and extension from the standpoint of these new requirements.

We may conclude by saying that the approach to the standardization and quality of testing of regenerated water cannot be considered independently of the place occupied by the water regeneration system in the general system of circulation of matter. Our view on this aspect is that with the further development of life-support systems based on biological processes associated with different sources and with different ways of utilization of regenerated water, the question /408
of establishment of hygienic standards for water must constitute only part of the general problem of its "ecological standardization."

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